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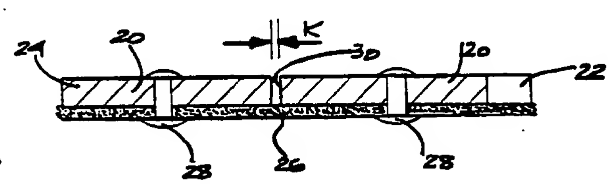
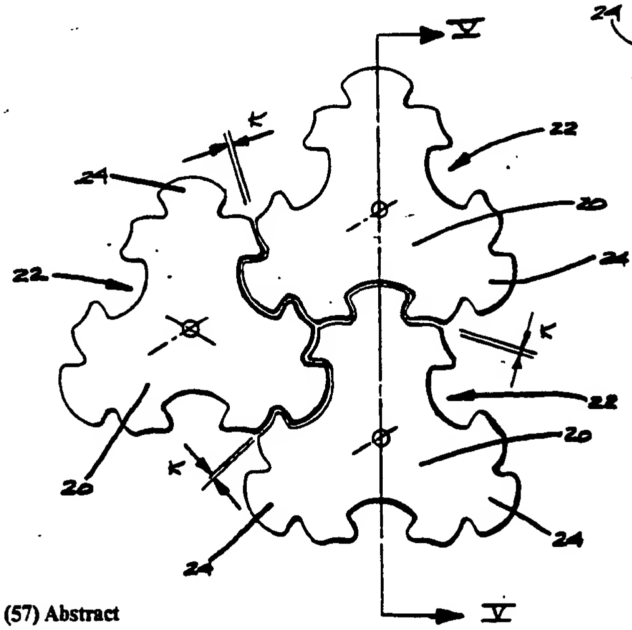
(54) Title: ARMOUR TILES AND FLEXIBLE ARMOUR COMPOSED OF SUCH TILES





(57) Abstract

A sheet material suitable for use in body armour and resistant to penetration by a knife blade comprises a flexible layer (26) to which is attached a plurality of essentially identical substantially rigid plates (20). Each of the plates is based on a polygon and has, on successive sides, a waisted projection (24) and a re-entrant recess (22) configured to receive a waisted projection (24) of another like plate (20). The peripheries of the plates (20) thus interfit and the plates interlock to resist separation by movement in the plane of the plates. Each plate (20) is attached to the flexible layer by a rivet (28), or could be bonded hereto.

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Armour tiles and flexible armour composed of such tiles

This invention relates to sheet materials, to processes for making the sheet materials, and to body armour whenever incorporating such sheet materials.

The background to the invention, and embodiments of the invention, will particularly be described in relation to the field of body armour. The invention is not limited to this field, however, and other applications and uses for the material may well occur to the reader.

The police force, other law enforcement agencies, the armed forces, security personnel and others are all making increasing use of body armour to protect against bullets. Although at one time such armour was rigid and heavy, modern armour is required to be flexible and relatively light-weight to give the user freedom of movement, and to be gas permeable to reduce condensation during long periods of use. The armour is usually in the form of a vest or panels made from a material resistant to penetration by a bullet and contained in a washable slip. The bullet-resistant material is usually a plurality of layers of a textile material woven from a ballistic grade of aramid fibre.

Although as a bullet resistant armour the known material is generally fairly satisfactory, it gives almost no protection against penetration by a knife blade. There are many rigid materials which are resistant to penetration by a knife blade, but previous research has failed to discover a material which is knife-proof, light-weight, flexible, gas permeable and suitable for use as body armour. Thus users of body armour remain unprotected against knives, which is of great concern to the police and to security personnel, for example in places of entertainment.

Against this background a first aspect of the

invention provides a sheet material suitable for use as or in body armour, which comprises a relatively flexible layer and a layer of relatively rigid interfitting and interlocking discrete plates each of which plates is attached to the relatively flexible layer.

Material constructed in accordance with the invention may be produced in many different grades and is expected to have diverse uses, but the material is especially suitable for use in the manufacture of body armour. The material of the rigid plates may be selected to be resistant to penetration by a knife blade, and the flexible layer may be selected to have suitable gas permeable properties, the overall material then being gas permeable because the relatively rigid layer is in the form of discrete plates, between which gas may penetrate.

Surprisingly, the sheet material can be very flexible even when the layer of relatively rigid plates is quite thick. The degree of flexibility is determined by the thickness of the plates in relation to their size in the plane of the layer, and by the maximum separation between adjacent plates whilst remaining interlocked. For example, in a preferred embodiment, a sheet of relatively rigid material is cut to provide the interfitting and interlocking plates, which sheet may then look somewhat like a jigsaw puzzle. The flexibility is determined by the width of the kerf relative to the thickness of the sheet and by the size of the plates in the plane of the sheet. Thus the wider the kerf relative to the thickness of the sheet the greater the flexibility; and the smaller the plates relative to the width of the kerf and the thickness of the plates, the greater the flexibility.

When the material is used as or in body armour, there is a good chance that a knife blade will not

strike a joint between two plates, but if it does, separation of the plates is limited by the interlocking therebetween, so still preventing complete penetration of the blade, so long as the blade is thicker than maximum possible separation between the plates. In the case of moulded plates which are assembled together, the clearance can be controlled by appropriate configuration of the mould used to produce the plates. In the case of plates cut from a sheet, accurate control of the kerf width will control the maximum separation. Either way, both the flexibility of the sheet and the resistance to penetration by a knife blade may be controlled. Should the point of a knife blade strike the sheet between the two plates, the blade will be able to penetrate only to a very limited amount, which may be less than the thickness of the sheet, so that no injury at all is sustained by the wearer.

The size of the plates in the plane of the sheet can be varied over the sheet. In body armour, an area of the sheet which is intended to cover the wearer's chest may have larger plates than an area of the sheet intended to cover the wearer's lower torso, which area would be required to be more flexible. Larger plates over, say, the chest, may assist in the reduction of injury resulting from the impact of a bullet, if the armour is also bullet resistant.

In a preferred form of the invention, the plates have the general overall shape of a polygon each side of which has either a waisted projection or a re-entrant recess configured so that a projection from one side of a plate interfits in an interlocking manner in the recess of an adjacent plate, whereby the extent to which adjacent plates can be separated is limited.

The polygon may be four sided with the result that the sheet resembles a conventional jigsaw puzzle. In a

more preferred sheet, each plate is based on a hexagon and has waisted projections and re-entrant recesses on alternate sides, arranged so that the sheet is made up from a plurality of like plates, all interfitted and interlocked together.

A relatively flexible layer is required on at least one face of the layer of plates and to which each plate is attached, in order to keep the sheet together. The plates may be bonded to the relatively flexible layer, for example by means of an adhesive. Alternative attachment techniques may be employed - for example by riveting each plate to the relatively flexible layer.

The invention is not limited to an arrangement of only one layer of relatively rigid plates and only one relatively flexible layer. For example, the sheet may include a second relatively flexible layer on the face of the layer of relatively rigid plates opposite the first-mentioned relatively flexible layer. In another arrangement the sheet may include a second layer of relatively rigid plates on the opposite face of the relatively flexible layer from the first-mentioned layer of relatively rigid plates.

Although other uses than body armour may be found for the sheet material of the invention, in order to provide knife-proof armour the plates are preferably made of one of the following materials: titanium; aluminium; steel; a ceramic; a thermosetting plastic or thermoplastic material, which may be filled or contain a reinforcing material; wood; laminated wood; or other composites of fibrous material and synthetic resin systems.

A sheet material constructed in accordance with the invention may be useful for body armour which is to be bullet-resistant. To provide a bullet resistant material, the plates may be made of one of the

following materials: aramid fibres (e.g. Kevlar [Registered Trade Mark]); glass fibres; high performance polyethylene; a ceramic; steel; aluminium; or a polyester resin reinforced with carbon or glass fibres. Of these, a ceramic, steel, aluminium, titanium and a resin system reinforced with glass fibres may also provide useful protection against knives. Armour which is both bullet resistant and knife resistant would be especially valuable.

In order to provide good gas permeability, the relatively flexible layer, or each such layer if there is more than one, may be made from a woven or non-woven textile material or a porous sheet-plastics material. Other materials may be used such as a metal mesh, a natural or synthetic rubber material, or a foamed plastics sheet.

The side edges of each plate, formed for example by cutting of a sheet or by moulding of the plates, may be normal to the principal faces of each plate, or may be at a selected acute angle thereto. By having the side edges at an acute angle may provide added protection against knife thrusts normal to the layer.

A second aspect of the invention extends to a process for manufacturing a sheet material in accordance with the first aspect, including the steps of forming cuts through a relatively rigid sheet to form said plates in an interfitting and interlocked relationship, and then attaching said interfitted and interlocked plates to said relatively flexible layer without disassembling the plates.

In a preferred process the sheet is cut to form the individual plates without dissembling them, by using a water-jet cutter though other tools may be used such as a jigsaw or a laser cutter.

The sheet may be cut flat and given sufficient flexibility for the intended use by suitable control of

the maximum possible separation of the plates. Thus, in the case of body armour, the sheet would need to be sufficiently flexible to form to and flex with a user's body. In other arrangements, the sheet may be preformed to have a two or three dimensional profile, before cutting. Thus in the case of body armour, the sheet may be preformed to the shape of a generalised torso before being cut. Thermoplastic materials could be formed in this way by the application of heat, whereas thermosetting materials could be moulded to have the required shape. High vanadium content titanium may be cold-formed to the required shape.

This invention extends to body armour made from or incorporating sheet material constructed in accordance with the invention as described above, or by a process of the invention also as described above.

By way of example only, certain specific embodiments of the invention will now be described, reference being made to the accompanying drawings, in which:-

Figure 1 is a plan view of a portion of a first embodiment of sheet material embodying the invention;

Figure 2 is a cross section of the material of Figure 1;

Figure 3 is a plan view of a second embodiment of plate for use in constructing a sheet material from a plurality of essentially identical rigid plates;

Figure 4 is a view on three interlocked plates of Figure 3, but separated by the maximum possible extent in the plane of the layer;

Figure 5 is a section taken on line V-V marked on Figure 4;

Figures 6A to 6D show alternative abutting edge configurations between adjacent plates;

Figures 7A to 7C show alternative multi-layer arrangements;

Figures 8A and 8B show two further alternative multi-layer arrangements; and

Figures 9A and 9B are respectively a front view of and a cross-sectional view through a body armour panel, incorporating a sheet material of this invention.

Referring initially to Figures 1 and 2, the sheet material comprises a relatively flexible layer 2 which may be a textile material or a sheet plastics material. The layer could be laminated, for example from different materials, but should remain relatively flexible.

Bonded to the relatively flexible layer 2 is a layer of individual plates 4 each of relatively rigid material, bonding being effective over the entire interface between the layers. The plates 4 interfit with each other so as to cover the layer 2 without substantial gaps between the plates. There is, however, clearance between the plates, as will be explained below. The interfitting shapes of the plates 4 also interlock so that the plates may not be separated by movement in the general plane of the layer.

Each plate is in the general form of a four-sided polygon, but each side is formed with either a projection 6 or a recess 8. Each projection has a waist 10 corresponding to a narrow mouth 12 of each recess which is consequently of re-entrant shape, opening out to a wider portion 14 corresponding to the wider portion 16 of a projection 6. Interlocking between adjacent plates is thus provided since it is not possible to remove the projection from its recess in the adjacent plate without lifting one of the pieces out of the general plane of the layer, but this is prevented by the bonding of the plates to the flexible layer 2.

If the plates were a tight interference fit, the

material as a whole would hardly be flexible. However, by having clearances between the plates, as illustrated, the layer becomes flexible. With such clearances, one plate can tilt relatively freely relative to the adjacent plate until its projection 6 jams in the associated recess 8. The larger the clearance relative to the thickness of the plates, the more flexible will be the layer. The smaller the plates relative to their thickness and the clearance, the more flexible will be the layer. In one example, each plate 4 was made of laminated wood 4mm thick and with a shape generally like that illustrated with about 5 mm sides. When assembled, an all round clearance of 0.177 mm (0.007 inch) produced a very flexible sheet.

Each plate may be made from a relatively rigid material, selected for example from metals such as titanium, aluminium or steel, or from a ceramic, or a plastics material or synthetic resin systems which may be filled or reinforced with fibrous materials such as glass fibres, carbon fibres, or aramid fibres. Other suitable materials include laminates of the aforementioned materials, and of wood.

Depending upon the material from which the plates are manufactured, they may be produced by injection moulding techniques, or by a cutting operation on a sheet of a suitable material. For example, a sheet of high-vanadium titanium may be cut along the convoluted paths X,X' and Y,Y' (Figure 1) in two directions generally at right angles, removing a kerf of a constant width K. The sheet may be cut using any suitable tool, such as a jigsaw, a laser cutter, or a water-jet cutter in which a very high pressure narrow jet of water is fired in a controlled manner at the sheet. An advantage of water-jet cutting, especially for a material like titanium, is that there is no heating of the workpiece, so there is no risk of

creating a heat-affected zone.

The width of the kerf should be very accurately controlled, because that width affects both the flexibility of the finished sheet, as explained above, and the degree to which the plates may be separated by, say, a knife blade forced between two plates.

Figure 3 shows an alternative configuration for a plate which may be used in the construction of the sheet material of the present invention. Each plate 20 is based on a hexagon identified by lines 21, with each side having either a re-entrant recess 22 formed therein, or a wasted projection 24 extending therefrom, the recesses and projections being arranged alternately around the hexagon and being similar to those described above with reference to Figures 1 and 2. As will be appreciated from Figure 4, a sheet of plates may be assembled from a plurality of identical plates 20 which both interfit and interlock, with only a very small clearance K between the plates and so that the plates cannot be separated in the plane thereof.

In Figure 4, three adjacent plates of the kind depicted in Figure 3 are shown interlocked together, but illustrating the clearance therebetween when the plates are separated in the plane of the plates, to the maximum permissible extent. Figure 5 also shows that clearance K between the two plates 20, but on an exaggerated scale for clarity. By virtue of that clearance, the plane of one plate may be tilted to lie at an angle to the planes of the next adjacent plates, whilst still remaining in an interfitting and interlocking relationship with the other plates. In this way, the sheet material may be flexed as required.

Also shown in Figures 4 and 5 is an alternative technique to bonding, for attaching each plate to the relatively flexible layer. Here, each plate 20 is separately riveted to the flexible layer 26 by means of

individual rivets 28 arranged substantially centrally of each plate and passing through pre-formed holes through the plates.

Figure 5 shows plates 20 having side edges 30 lying normal to the plane of the principal faces of each plate, but Figures 6A to 6D show alternative side-edge configurations, to reduce the likelihood of a knife blade penetrating between two adjacent plates. In these Figures, like components or components performing a similar function are given like reference characters and will not be described in detail in connection with each Figure.

In the arrangement of Figure 6A, the side edges 32 and 34 of two adjacent plates 36 are disposed at substantially the same non-perpendicular angle to the flexible layer 38 and the plates 36 are thickened in the region of the abutting side edges. The thickened portions of the plates tend to direct a knife blade tip away from the interface between the two adjacent sheets; and the thickened portions in conjunction with the angled interface gives a greater interface length, to assist the resistance to penetration of a knife blade.

The plates 36 shown in Figure 6A may be identical, and be for example shown in Figures 3 and 4. It will be appreciated that the angle a side edge 32 or 34 makes to the principal face of the plate must change, at different points around the periphery of the plate. Thus, at one point (for example on a projection 24) the side edge may lie at an obtuse angle to the flexible layer 38; at another point (for example, within a recess 22, to match a projection) the side edge may lie at an acute angle to the flexible layer; and at other points (for example between projections and recesses) the side edge may lie at right angles to the flexible layer 38.

The Figure 6B arrangement has bevelled corners 39 between the principal faces of the plates 36 and their side edges 40. This bevelling allows the maximum permissible clearances to be reduced, without reducing the overall flexibility of the sheet.

In Figure 6C, a relatively thin and flexible web 42 is left by the cutting process, interconnecting the two plates 36. This web 42 positively restricts separation of the plates without significantly impairing flexibility of the sheet.

The arrangement of Figure 6D corresponds to that of Figure 6A, except that the plates 36 are not thickened in the region of the interface therebetween.

Figure 7A shows a three-layer construction which may generally correspond to that of Figures 1 and 2, or to that of Figures 4 and 5, except that there are two layers of plates 44, arranged one on each side of the flexible layer 46. The plates of each of the two layers may be aligned as shown, or the plates could be out of registration, so giving staggered joints. In the arrangement of Figure 7B, two flexible layers 48 are provided one on each face of the layer of plates 50.

The arrangement of Figure 7C corresponds to that of Figure 7A, except that the abutting side edges of the plates in each layer are configured as shown in Figure 6B.

Figures 8A and 8B both show multi-layer arrangements, having three flexible layers 52 and three layers 54 of rigid plates. In the arrangement of Figure 8A, the plates of each layer are in registration with the plates of other layers, whereas in the arrangement of Figure 8B, the plates of the central layer are out of registration with the plates of the upper and lower layers. Though there may be a significant loss of gas permeability in the arrangement

of Figure 8B, the overall sheet material may demonstrate a greater resistance to penetration by a knife blade thrust between adjoining plates.

Figures 9A and 9B show a part of a typical body armour intended to protect the chest or back of a user. This armour comprises an outer layer 56 of a textile material, an inner layer 58 which may typically be of the same textile material, and disposed between those inner and outer layers, a sheet material 60 of this invention and which may thus correspond to any of the embodiment described above. Between the faces of that sheet material 60 and the outer layer 56, there is a number of layers 62 of a loosely-woven aramid textile, which layers offer essentially no resistance to the penetration of a knife blade, but nevertheless exhibit great resistance to penetration by a bullet.

The body armour may be completed by providing a back panel of a generally similar construction to that illustrated in Figures 9A and 9B, which back panel is connected to the front panel by suitable ties (not shown) or by strips of hook-and-loop fasteners, one part of which is furnished on each panel as shown at 64.

It will be appreciated that the various embodiments of sheet material of this invention as described above all are capable of offering resistance to penetration by a knife blade, in view of the interfitting and interlocking relationship of the rigid plates lying in at least one layer of the sheet material. The material may be relatively thin and exhibit considerable flexibility, so rendering it particularly suitable for use in a panel of body armour which, in use, may be light-weight and comfortable to wear.

CLAIMS

1. A sheet material, comprising a relatively flexible layer and a layer of relatively rigid interfitting and interlocking discrete plates each of which plates are attached to the relatively flexible layer.

2. A sheet material as claimed in claim 1, wherein the plates have the general overall shape of a polygon each side of which has either a waisted projection or a re-entrant recess configured so that a projection from one side of a plate interfits in an interlocking manner in the recess of an adjacent plate whereby the extent to which adjacent plates can be separated by movement in the general plane of the sheet is limited.

3. A sheet material as claimed in claim 2, wherein the plates are based on a four or six-sided polygon.

4. A sheet material as claimed in any of the preceding Claims, and comprising a further relatively flexible layer attached to the plates on the faces opposite the faces attached to the first-mentioned relatively flexible layer.

5. A sheet material as claimed in any of the preceding Claims, and comprising a further layer of relatively rigid interfitting and interlocking plates attached to the relatively flexible layer on the faces thereof opposite that attached to the first-mentioned layer of relatively rigid plates.

6. A sheet material as claimed in Claim 5, wherein the peripheries of the plates in one layer thereof are out of registration with the peripheries of the plates in the other layer thereof.

7. A sheet material as claimed in any of the preceding Claims, wherein each plate has a peripheral

wall extending between the faces thereof, at least a portion of which wall lies at an acute angle to one of the faces of the plate.

8. A sheet material as claimed in any of the preceding Claims, wherein the plates are made of a material selected from the group of substantially rigid materials consisting of metals, ceramics, thermoplastics materials, thermosetting plastics materials, synthetic resins, filled or reinforced plastics materials, filled or reinforced synthetic resins, and composites and laminates of these materials.

9. A sheet material as claimed in any of the preceding Claims, wherein the relatively flexible layer comprises a woven or non-woven textile or a sheet-plastics material.

10. Body armour comprising a garment having inner and outer layers, and a sheet material as claimed in any of the preceding Claims disposed between said inner and outer layers.

11. A process for manufacturing a sheet material as claimed in any of Claims 1 to 9, including the steps of forming cuts through a relatively rigid sheet to form said plates in an interfitting and interlocked relationship, and then attaching said interfitted and interlocked plates to said relatively flexible layer without dissembling the plates.

12. A process as claimed in claim 11, wherein the sheet is preformed to have a three-dimensional profile before being cut to form the plates.

13. A process as claimed in Claim 11 or 12, wherein the sheet is cut by water-jet cutting process.

Fig 2

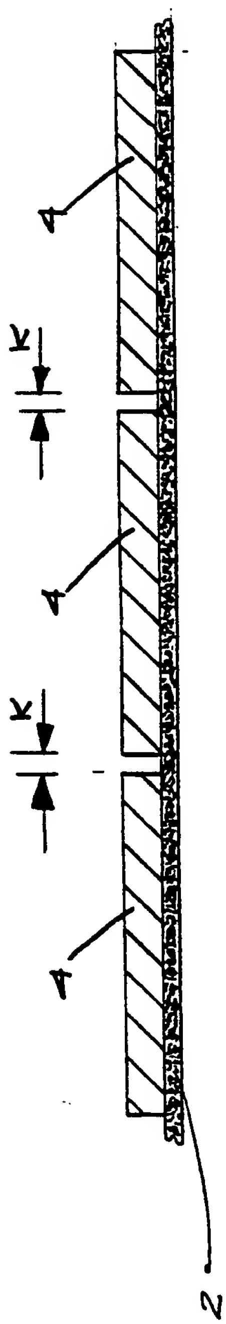
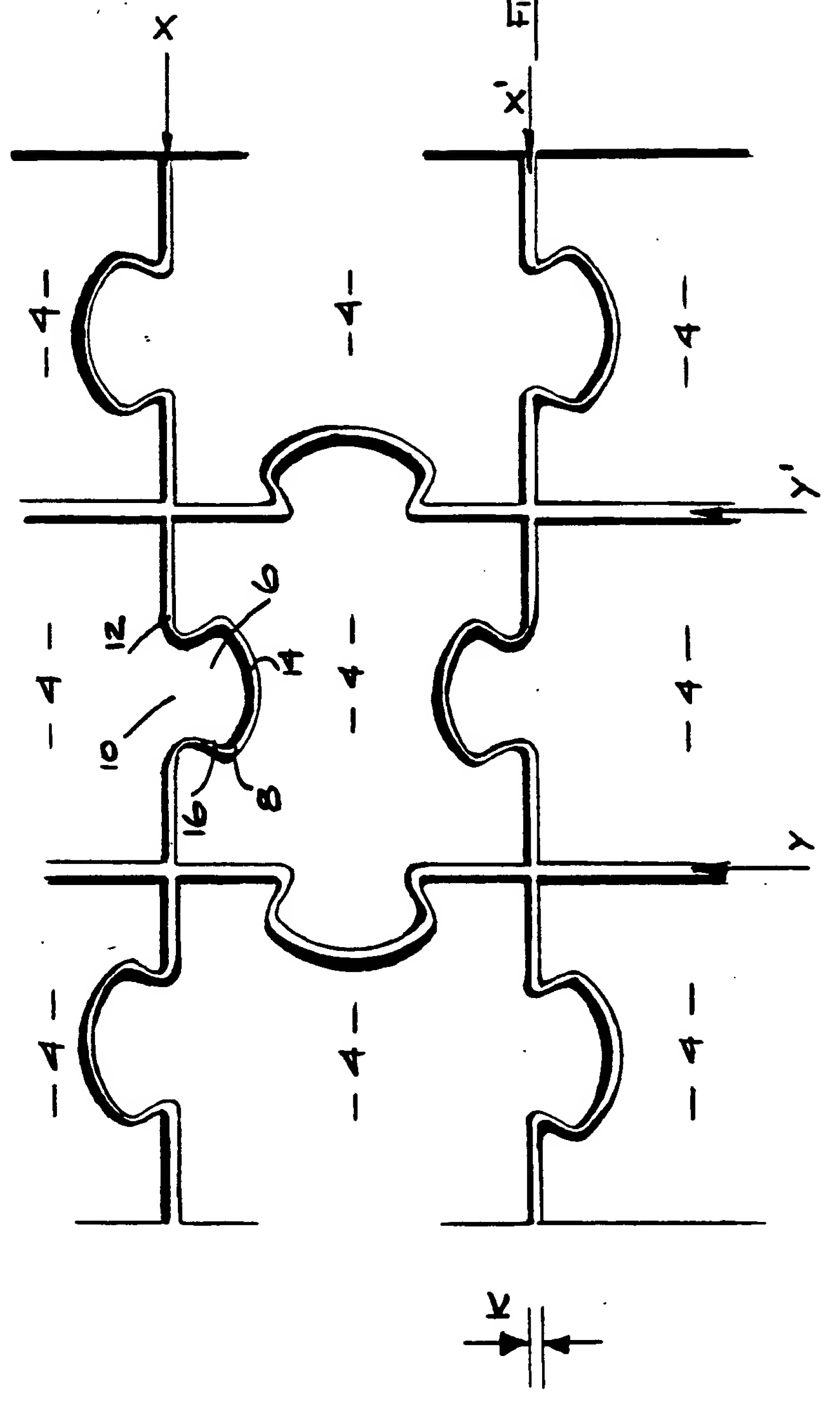


Fig 1



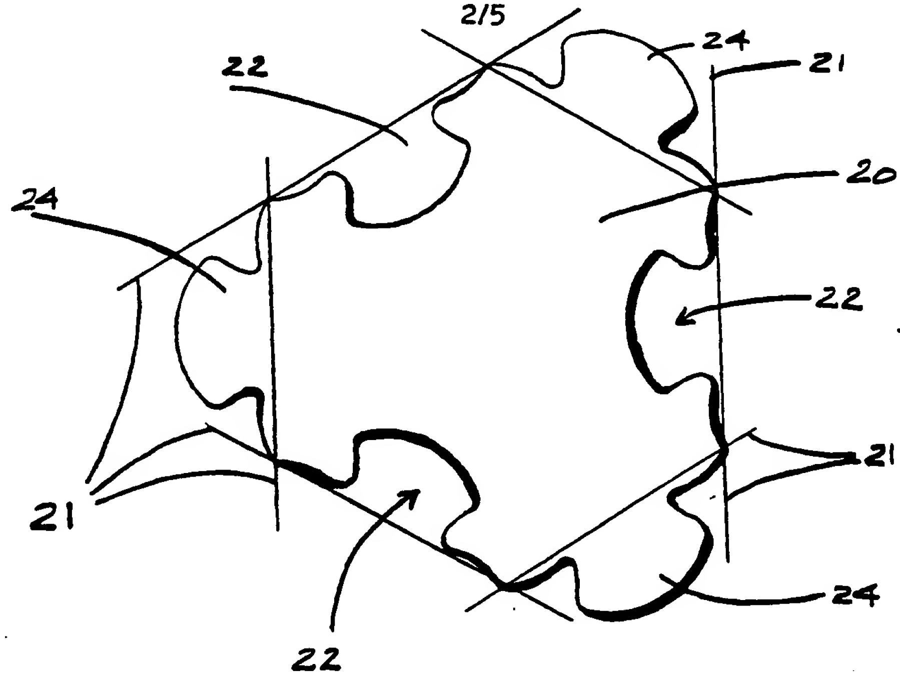


Fig 3

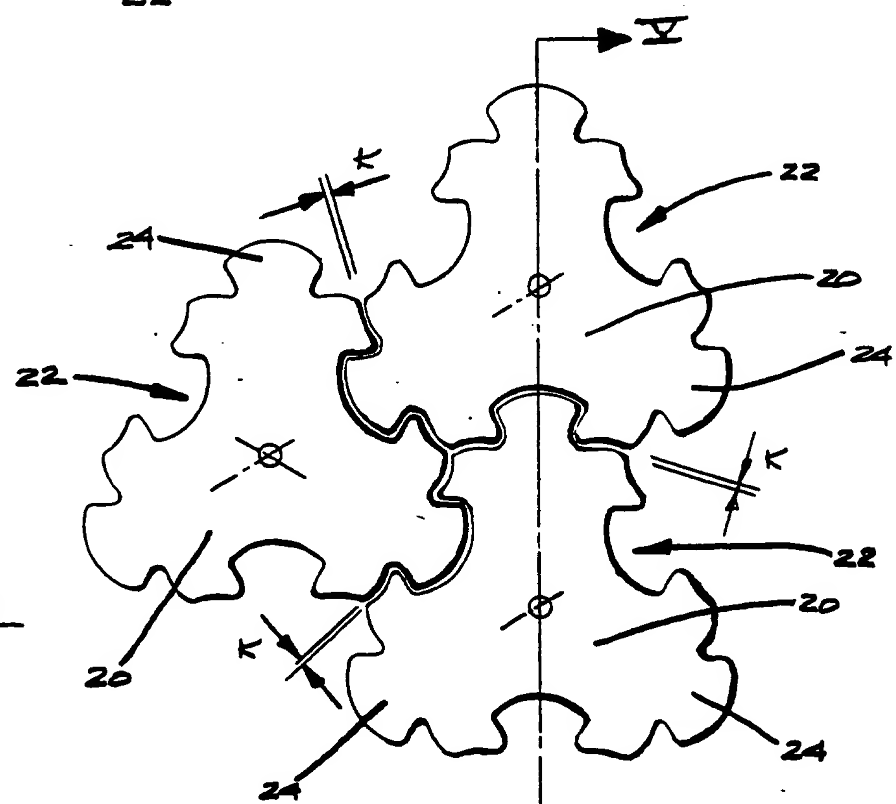


Fig 4

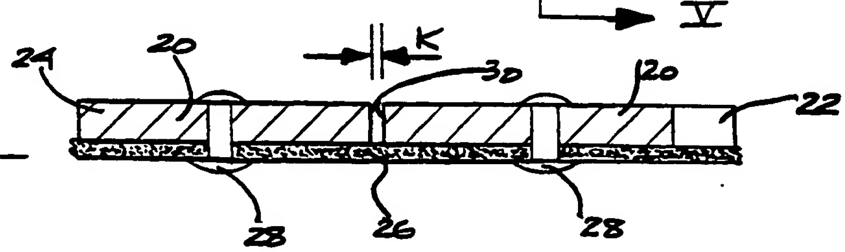


Fig 5

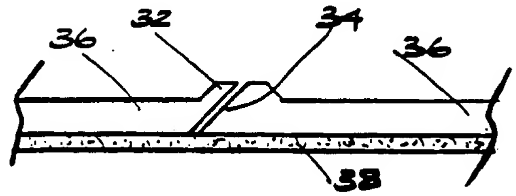


FIG 6A

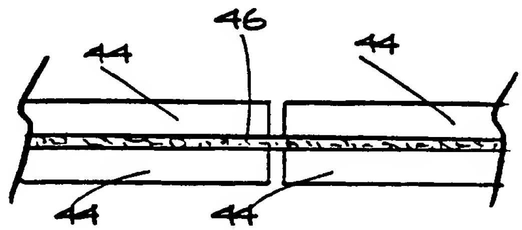


FIG 7A

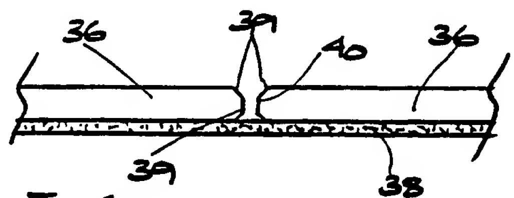


FIG 6B

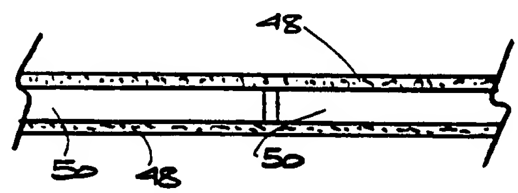


FIG 7B

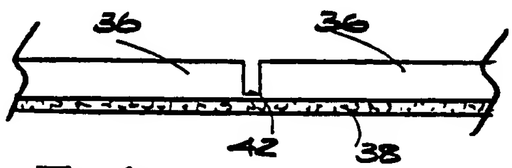


FIG 6C

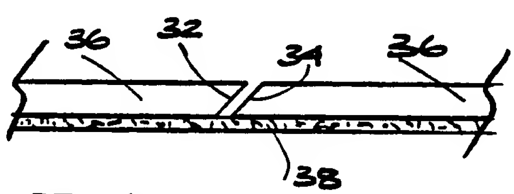


FIG 6D

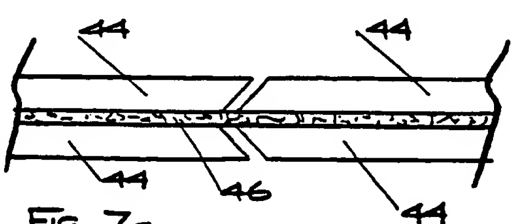


FIG 7C

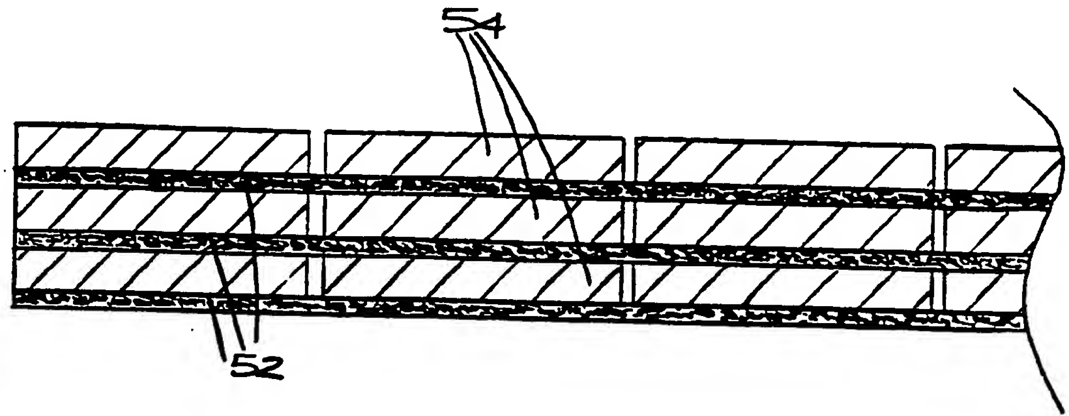


FIG 8A

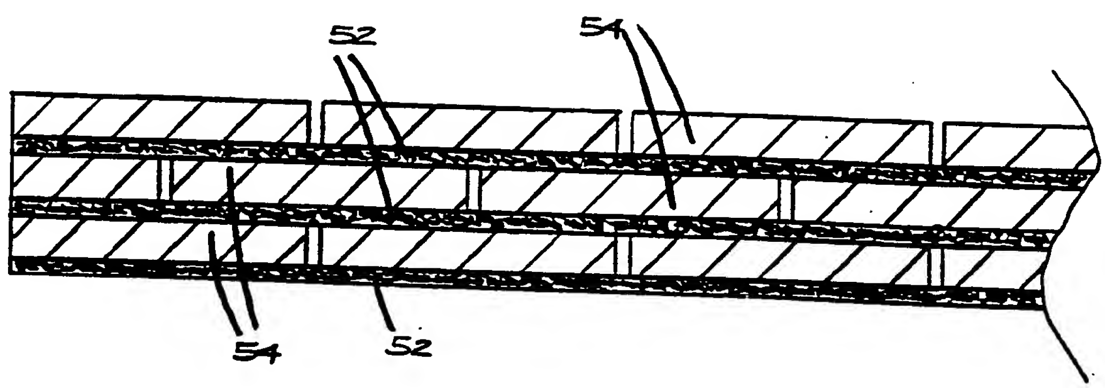


FIG 8B

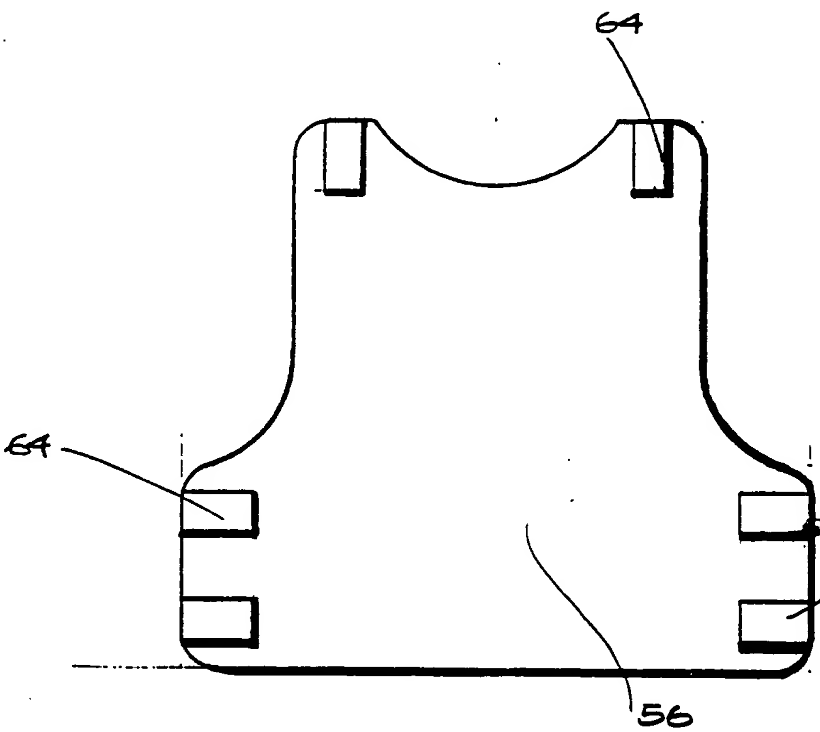


FIG 9A

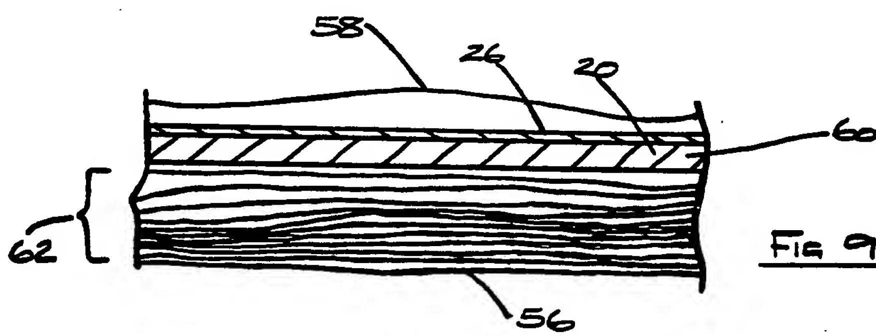


FIG 9B

INTERNATIONAL SEARCH REPORT

International Application No PCT/GB 93/00770

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)[6]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int.Cl. 5 F41H1/02; A41D31/00

II. FIELDS SEARCHED

Minimum Documentation Searched[7]

Classification System	Classification Symbols
Int.Cl. 5	F41H ; A41D

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched[8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT[9]

Category °	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No.[13]
X Y	GB,A,2 004 177 (ELTEKA KUNSTSTOFTECHNIK GMBH) 28 March 1979 see page 1, line 16 - line 73 see page 3, line 73 - page 4, line 31; claims; figures ---	1,2,7,8, 10 3-6,9
Y	US,A,3 867 239 (ALESI ET AL) 18 February 1975 see the whole document ---	3-6,9
X	US,A,4 483 020 (DUNN) 20 November 1984 see the whole document ---	1
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° Special categories of cited documents : [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

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1 **IV. CERTIFICATION**

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
29 JUNE 1993	27.07.93
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	DOUSKAS K.

Form PCT/ISA/210 (second sheet) (January 1985)

International Application No PCT/GB 93/00770

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
Category °	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.
X	DE,A,3 716 055 (DIEHL GMBH) 1 December 1988 see column 2, line 57 - column 3, line 38; claims; figures	1-3,8,9

Form PCT/ISA/210 (extra sheet) (January 1985)

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO. GB 9300770 SA 73116

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the European Patent Office EDP file on
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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
GB-A-2004177	28-03-79	DE-A- 2741180 CH-A- 634913 US-A- 4198707	22-03-79 28-02-83 22-04-80
US-A-3867239	18-02-75	None	
US-A-4483020	20-11-84	None	
DE-A-3716055	01-12-88	None	

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